RETURNS TO RESEARCH AND DEVELOPMENT SPENDING

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1. THE CONTRIBUTION OF RESEARCH AND DEVELOPMENT TO PRODUCTIVITY GROWTH

1.1 Research and Development (R&D) may be thought of either as a *flow* of spending or as a *stock* of accumulated knowledge from R&D expenditures which depreciates as new products or processes are introduced. The R&D conducted in one sector can have productivity-enhancing effects in the sector which performs the R&D either through cost reductions (process innovations) or market expansion (product innovations).

1.2 Besides generating returns to the performing sector, R&D benefits can spill over to other sectors for three main reasons.

- First, external benefits may occur because downstream users do not pay the full value of the input, as when banks purchase computers that are worth more to them than the price they pay for the machines. Also, quality improvements arising from R&D may not be reflected fully in higher prices because of competition in product markets.

- Second, a technical discovery or an innovation can inspire work in another company. Competitors may copy or adapt the new technology. New ideas may emerge, new avenues of research may be undertaken, or previous results may become economical to pursue and bring to full fruition. For example, the invention of synthetic fibres by the chemical industry triggered many novel applications in the textile industry.

- Third, research and engineering staff may leave to join other companies or set up their own, taking their knowledge with them.

For all these reasons the innovating company cannot 'appropriate' all of the return to its own R&D: part of the benefit is obtained by its competitors, customers and employees and will not be captured. A distinction is thus made in the literature between private and social rates of return: economic returns which are appropriated by the R&D performer and returns which cannot be appropriated by the R&D performer but by society at large.

1.3 R&D can also contribute to productivity growth indirectly through its interaction with other inputs. If capital and R&D are complementary, increasing the R&D stock may open up new possibilities for profitable capital investment.

1.4 R&D performed in-house and R&D performed elsewhere can also be complementary. Many authorities have stressed the dual role of R&D as the capacity to learn and to absorb. Although knowledge is a public good it cannot be absorbed costlessly. Instead, depending on the type of knowledge and the characteristics of the firm, a certain level of internal R&D has to be conducted in order to create an absorptive capacity.

1.5 Finally, R&D can have indirect effects on productivity growth through the interaction of supply and demand. For example, R&D may reduce costs, which in turn lowers prices and increases quantities demanded. As demand and output expands productivity will be increased if there are increasing returns to scale.

2. SOME PROBLEMS IN ESTIMATING RETURNS TO R&D

2.1 The presence of spillover effects thus poses difficulties for researchers wishing to estimate a rate of return to R&D spending. Even without spillover effects the causal connection between R&D and ultimate market effects is often imperfectly observed. Several difficulties have to be overcome if useful estimates of the rate of return to publicly funded R&D are to be obtained:

- **R&D is one input in a complex and uncertain innovation process:** Other inputs are complementary and need to be included in descriptions of the production process; in general, there is no single model with which to assess and predict research results.

- **Public Sector outputs**: Some public sector outputs cannot be priced, eg national security, improved policy advice. While it may be possible to price some public goods, the revenues cannot be appropriated from users; moreover, the cost of servicing additional users is near zero (eg R&D to help produce cleaner air) thus the merits of a pricing mechanism are doubtful.

- **Lags**: R&D achieves returns at varying times in the future (see Table 1); high rates of discount will have the effect of reducing the present value of benefits to zero in many cases; in some cases discounting will have the effect of producing a negative net present value.

2.2 In the public sector most Departmental outputs cannot be measured in monetary terms. Departments have become adept at using performance indicators to proxy outputs but, while these are useful, they cannot be equated with monetary outputs.

3. MEASUREMENTS OF R&D RETURNS IN THE PRIVATE SECTOR

3.1 Most of the empirical work in this field has originated in the USA. There have been two types of research procedure: case studies and econometric work.

(I) CASE STUDIES

3.2 These studies employ a variety of approaches; most of them measure returns by means of an 'internal rate of return'* unless otherwise stated:

- Griliches (1958) estimated the economic rate of return to agricultural R&D in the USA over the 1910-55 period at about 35-40 per cent;

- Mansfield's (1977) work on 17 innovations in the US in the early 1970s estimated the private rate of return at about 25 per cent and the social rate of return at 56 per cent;

- Mansfield's (1991) work on the academic research results employed by 76 US firms in seven industries indicated the rate of return at between 22-28 per cent (per annum). This result has been queried by some observers (eg Smith, 1991) because of the rather crude methodology employed to obtain estimates (eg the cost denominator was the increment to R&D in one year rather than a depreciated stock of knowledge);

- Robb (1991) of General Electric (GE) in the United States has reported one of many single firm studies: GE commissioned Booz Allen to survey 190 "business transitions" dependent upon R&D over 1982-87 and estimated an internal rate of return of 20 per cent (with 50 per cent of the return obtained by only five cases).

3.3 Studies of the returns to private sector R&D have sometimes been criticised for producing inflated results because the cost of complementary inputs have not been included in the calculation of returns. On the other hand, most such studies cannot capture all the external (or spillover) benefits of research, because they are in unrelated fields, or because the innovator is too far from the ultimate beneficiary in the production->consumption chain. This may result in an under estimate of the returns.

* *The discount rate which, when applied to the future stream of net benefits, provides an exact balance between initial R&D costs and prospective net benefits.*

3.4 It might be considered instructive to contrast these private sector rates of return to R&D with rates of return obtainable from other investments, for example, in respect of fixed capital, marketing facilities, etc. Unfortunately, there is no reliable information on a range of alternative investments. There are data on typical *hurdle* rates in British industry. For example, Pike (1982) found that 40 per cent of respondents used a hurdle rate of 20 per cent or over for normal risk projects. Scapens and Sale (1981) found average rates of 18.5 per cent in the UK and 17.1 per cent in the US in their survey. Also, in the opinion of Hayes and Garvin (1982), hurdle rates 'are typically quite high, often in the range of 25% to 40%, and there is some evidence that they have been rising over the past decade'. But such hurdle rates are essentially ex ante barriers intended to screen out poorly performing investments rather than indicators of ex post rates of return. They usually include allowances for risk, inflation, and some non-yielding overhead investments that have to be 'carried' by positive yield investments (Coulthurst, 1986).

(II) ECONOMETRIC WORK

3.5 In general, researchers estimate a multi-variable production function in order to take into account the impact of several inputs, including R&D. Griliches (1986, 1987) the main exponent of this approach finds that: (i) the stock of R&D capital contributes significantly to cross-sectional differences in productivity between sectors; (ii) the effect of basic research in the private sector is positive and significant; (iii) privately financed research has slightly higher returns than federally funded research. On average the rate of return equivalents estimated from Griliches' work were 51 per cent for 1967 and 62 per cent for 1972, reasonably comparable with the social returns obtained from Mansfield's early work.

3.6 Griliches summarises the vast range of literature in this field as indicating a gross rate of return in the range 20-50 per cent. Möhnen (1990) confirmed two of Griliches' results. First, there is a higher rate of return for basic R&D compared with applied or 'development' R&D. This finding is not surprising: private firms perform relatively little basic research, and there are more opportunities for spillover benefits from basic research. Moreover, basic research costs are relatively low compared with applied research and development costs; and, once it is clear that a line of enquiry is not promising, projects can be terminated without demonstrable adverse effects (Morris et al, 1991). Second, there is a higher rate of return on company-financed as opposed to publicly financed R&D. Again, this result is not unexpected because much publicly financed R&D is in areas where the risks involved are relatively high.

3.7 Several studies suggest that inter-industry differences in returns to R&D are significant; and that such differences tend to be greater than inter-country differences. Ranking industries in descending order of rate of return from R&D (*based on the US and Canadian literature*) shows the following: rubber and plastics, scientific instruments, petroleum, non-electrical machinery, primary metals, chemicals, gas and oil exploration, electricals, metals fabrication, food and beverages, pulp and paper, transport equipment, and aircraft and parts.

4. SUMMARY OF LITERATURE FINDINGS ON PRIVATE SECTOR R&D

4.1 R&D has been identified as an important determinant of productivity growth. The evidence suggests that the private (net of depreciation) rate of return lies in the 10 per cent to 40 per cent range.

4.2 R&D is to a large extent a public good that may be consumed by other firms in the same industry, and by other industries in the same country; it can also spill over country borders. These spillover effects can be substantial. Social rates of return 50 per cent to 100 per cent in excess of the private rates of return are not uncommon.

4.3 The mix of R&D is of some importance. It is now accepted that higher rates of return are obtained from company-financed R&D rather than publicly-funded R&D; this may be because the objectives of publicly-funded R&D are systematically different from the aims of privately financed R&D. Social rates of return to industrial R&D are highest in sectors such as chemicals, non-electrical machinery or scientific instruments. Policy-makers should not be insensitive to the type of R&D being funded or encouraged.

5. RETURNS TO GOVERNMENT R&D

5.1 The economics literature has approached the assessment of returns from R&D at the aggregate level by asking the question: what is the relationship between technological change (directly and indirectly measured by R&D) and economic growth? The earliest studies, by US economists studying growth in the first half of the present century, suggested that growth arising from technological change was about 1.5 per cent per annum. On the basis of this finding, it was concluded that about 90 per cent of the increase in output per capita during this period was attributable to technological change. The basic methodology used in these early studies was as follows: the total output of the economy arises from various inputs of productive services into the productive process; these inputs can be identified as labour and capital and attempts may be made to estimate their contribution to the measured growth of output; whatever portion of the measured growth of output cannot be explained by these inputs may be attributed to technological change. The crudeness of this procedure is transparent. The resulting measure of the effect of technological change contains the effects of whatever inputs are excluded which may be increases in economies of scale, an improved allocation of resources, increases in education, or improved health and nutrition of the labour force.

5.2 Later work has gone some way to remedy this shortcoming. For example, Denison (1967) included many inputs - particularly changes in labour quality associated with increases in schooling - omitted in earlier studies. Denison concluded that technological change, or what he termed the "advance of knowledge", accounted for about forty per cent of the total increase in US national income per person employed during 1929-1957. Subsequently, he estimated that the advance of knowledge was responsible for 1.4 percentage points of the annual growth rate of national income per person employed during 1948-1969, and for 1.6 percentage points of its growth rate during 1969-1973. It is acknowledged that this body of work still has some defects. Nevertheless, based on the available evidence, technological change seems to have been a very important factor, perhaps the most important factor, underlying long-term economic growth in the United States and elsewhere.

5.3 This work has generally been taken to undergird the case for public sector funding of R&D. Because aggregate studies have shown a healthy positive effect of technological change on economic growth, and because the public sector has supported investments in technological change (as well as investing heavily in the "advance of knowledge"), Governments have argued with some force that their R&D investments have contributed to wealth creation.

5.4 In contrast, public sector microeconomic studies are pessimistic about the possibility of estimating returns to R&D at the departmental or programme

level. For example, Paul (1992) distrusts the calculation of economic returns even within industry where research is sharply focused on processes or products. Given the *time lags* and the absence of reliable *data on supplementary inputs* (that is, the types of inputs used by Griliches and others in econometric work) Paul states: "... typical cost benefit analyses can, at best, be indicative and, at worst, spurious." He also takes the view that "... attempts to evaluate the work purely on ex-post financial criteria may not only be inaccurate but also misleading." However, Paul recommends the use of non-financial allocation criteria which are reasonably systematic: scoring models, return on investment in specific industry cases where reliable market data are available, and research effectiveness indicators (see Section 6.). These may be used as indirect indicators of the rate of return.

5.5 In the USA an Office of Technology Assessment (OTA, 1986) study came to broadly the same conclusions. The OTA suggests three fundamental reasons why precise measurement of R&D outputs is difficult:

(i) Non-economic aims, such as defence, where the aims are to encourage socially desirable, high risk investments which the private sector will not, or cannot, handle;

(ii) Problems of benefit measurement, for example, in health advances, where realistic market prices are not set; consequently returns do not accrue to the investor and tend to spill over into other sectors;

(iii) Many outputs are available at zero marginal cost and zero price; to collect revenues would cost more than the cost of production.

5.6 The OTA believes that Governments cannot employ a private sector methodology to assess monetary returns to publicly funded R&D. However, the OTA admits exceptions, namely:

(i) **agricultural R&D**: see above Griliches (1958). These findings were replicated by many others (see Table 2). However, some agricultural economists are less sanguine about the work in this area since the environmental impacts of agricultural advance have become more pronounced.

(ii) **aviation**: where Mowery (1985) has estimated internal rates of return in the range 24-27 per cent;

(iii) **health**: where Mushkin (1979), using a human capital approach, obtained an internal rate of return in the 40-50 per cent range.

5.7 One other point made by the OTA is worth noting here. It is that all of the production function models employed to estimate returns to R&D, both in the public and private sectors, do not necessarily demonstrate causality. For example, the finding obtained by Griliches in respect of basic research in the private sector might be explained by rich successful companies being able to indulge themselves in basic research. However, it is not possible to dismiss such a large body of work out of hand by alleging reverse causality. So many researchers have replicated these results (including some who have tested for reverse causality), and so many private sector firms invest in R&D with the clear expectation of gain, that the argument concerning reverse causality is very weak . As the Organisation for Economic Co-operation and Development (OECD, 1991) has observed: "It is therefore an agreeable surprise to discover that most studies have managed to produce statistically significant and frequently plausible estimates of the elasticity of R&D or the rate of return to R&D. Individual case studies and other factual knowledge in the field, as well as the fact that firms do indeed undertake research, leave little room for doubt on this score."

5.8 For the UK, there is scattered evidence of the use of cost benefit analysis (CBA) techniques in Departments, but the same problems noted by the OTA and Louis Paul have been encountered. There is a wealth of evidence that departments have employed CBA to assess (ex ante) or evaluate (ex post) investment programmes: in agriculture, forestry, flood defence systems, fisheries vessels, the Third London Airport, road improvements, office relocation, overseas aid projects, etc; and cost-effectiveness studies are a commonplace in health and defence.

5.9 However, these are not all areas where R&D is very important. In **Health**, R&D can play a major part in preventing or reducing disease but there are still undecided questions about the valuation of benefits; and clinical research has uncertain pay-offs over long periods. There have been attempts at relating **agricultural** R&D to productivity improvements, both in the Ministry of Agriculture, Fisheries and Food (MAFF) and in the National Institute of Agricultural Engineering. These attempts have never proceeded to specify an overall departmental rate of return.

5.10 One interesting approach in the public sector is that of the Bureau d'Economie Théorique et Appliqué (BETA) group in Strasbourg. For example, this group has sought to calculate the indirect economic effects of the European Space Programme (Bach and Lambert, 1993). The methodology distinguishes between technological, commercial, organisational and work factor effects and quantifies these in terms of 'added value' (meaning the sum of the wages and

profits of firms receiving contracts from the European Space Agency (ESA)). Managers were asked to estimate co-efficients which attributed the contribution made to sales by the four effects listed above and estimated the contribution of ESA work to those effects. The process was extended to firms which supplied the contractors. A figure was produced which represented the ratio between: the total value of indirect effects generated by the ESA contractors, and the total payments made by ESA to those contractors. Criticisms of the method have focused on its potential for subjectivity, the failure to consider investments needed after the technology is developed, and the failure to discount future benefits. The approach has recently been applied to two of the EC's programmes (Basic Research in Industrial Technologies for Europe and European Research in Advanced Materials (BRITE, EURAM)) and yielded a highly positive ratio.

5.11 Finally, it is worth noting that defence R&D spending has been assessed in terms of the defence industry's contribution to output, employment and the trade balance. For example, Table 3 shows how the UK aerospace industry, and the trade in military aircraft and parts, contributed to the visible trade balance during the period 1981-91. It is clear that over the decade the UK aerospace industry was in surplus with the rest of the world and there are grounds for suggesting that the trend in the balance was slightly positive. However, these data do not imply that the rate of return on aerospace R&D investments was positive. It seems likely that the rate of return on privately funded aerospace R&D was positive; but support for aerospace R&D in the form of Launch Aid (payments net of the present value of Launch Aid receipts) will have increased the total spend on R&D. To that extent, the rate of return on total aerospace R&D spending, from both private and public sources, will have been reduced.

5.12 **In summary**, broad assessments of the return to R&D spending by the public sector are possible at the aggregate level. And at the individual project level there are several examples, both in the UK and overseas, of reasonably firm estimates of returns. However, at the intermediate level of the overall programme, or Departmental, spend the problem of attributing returns to an eclectic collection of projects, many of which have long gestation periods or non-financial policy objectives, has posed grave difficulties for research.

6. SYSTEMATIC EX ANTE ASSESSMENT OF R&D

INTRODUCTION

6.1 The previous sections reviewed attempts to assess quantitative *ex post* rates of return to R&D; the subject of ex ante assessment is now discussed. In one sense, *ex ante* assessment must be performed before almost any decision is taken on the allocation of resources to R&D. This can take place at several different levels of aggregation ranging from national technology priorities, to the organisational, programme or portfolio level, and to the level of project selection. Approaches too may vary, addressing issues such as:

- how much R&D to perform; and

- how to allocate resources by some mix of informal judgement and decision aids.

Here the focus is primarily on more systematic approaches, in particular those which are concerned with investment decisions. Inevitably, much of the experience in this area has been accumulated in the private sector where almost all R&D spending is made with a view to economic return. However, *ex ante* assessment is also being given increased prominence in the public sector. Some of the methods and techniques available to firms are described and their strengths and limitations are discussed, together with some new developments. The report concludes with some lessons for government R&D.

PUBLIC SECTOR EXPERIENCE: APPRAISAL

6.2 The practice of performing a formal appraisal of an R&D programme or project before it is selected is now well established in UK government. As defined in the Cabinet Office publication, *R&D Assessment - A Guide for Customers and Managers of Research and Development*, programme appraisal is directed at establishing whether there is a need for the R&D concerned, defining the programme and its objectives, and culminating in a statement of justification. The most widely used approach is one initially developed in the Department of Trade and Industry, the ROAME system. ROAME (an acronym for Rationale, Objectives, Appraisal, Monitoring and Evaluation) is a discipline which seeks to establish rationale and objectives and to state how programmes will be appraised, monitored and evaluated. It is relevant to this discussion because it could provide a suitable framework in which to locate appraisal of the likely economic returns to R&D spending.

6.3 The ROAME style approach can be complemented by the use of logical frameworks which make more explicit the connections between objectives and expected outcomes and often specify verifiable levels of attainment. Logical frameworks were originally applied for development projects and their use is most extensive in the Overseas Development Administration.

6.4 Approaches of this type are also used overseas, notably in Canada where evaluations of government-funded R&D make extensive use of the 'logic chart' approach which relates programme objectives and activities with upward links to higher level objectives and downward links to expected impacts. Recently, the emphasis in Canada has been on the development of 'performance expectations', an approach which defines strategic and desired levels of performance with a direct link to the objectives of the programme.

CRITICAL TECHNOLOGIES EXERCISES

6.5 At a higher level of aggregation recent efforts in several countries to identify 'critical technologies' have entailed an element of economic assessment, typically involving an intersection between technological promise and potential market impact. For example, the approach adopted by the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO), subsequently replicated in New Zealand, aimed to assess the potential benefits to Australia of research in different areas and to identify factors relevant to the achievement of those benefits. CSIRO used four criteria in assessing whether a technology was critical:

- the potential economic and social benefits;
- Australian capability to achieve those benefits;
- R&D potential and costs;
- Australian research capability.

The Australian study incorporated ways of scoring to enable two market-oriented parameters to be derived, **attractiveness** (benefits and the potential to achieve them) and **feasibility** (R&D potential and capability). Although outside information was used, the expertise drawn upon was primarily from within CSIRO. The outcome was presented in the form of a graph which enabled the position of the selected technologies to be seen readily and a form of ranking to be set out. This study and other exercises represent a means of ordering expert opinion in a systematic manner; they do not attempt to provide a precise measurement of the rate of return.

6.6 One feature of the CSIRO approach which might be stressed in any United Kingdom procedure is the assessment of regional appropriability of benefits. It may not be sufficient simply to identify potential returns from a piece of R&D; it may also be necessary to demonstrate that these returns would accrue to the United Kingdom. This would, for example, exclude benefits arising from research in an activity where industrial capability lay exclusively overseas and where barriers to entry made it unlikely that UK industry would be able to enter the market.

6.7 Another lesson to be derived from the experience of critical technologies exercises is that most of the technologies selected are inter-related and pervasive, that is they underpin a wide range of other technologies and economic activities. Indeed, this pervasive characteristic is one reason why public support is justified. It follows that any attempt to estimate the benefits arising must take account of these relationships. Matrix methodologies have been developed to track these relationships and identify pervasive areas of science and technology (Lowe and Georghiou, 1989).

COST BENEFIT APPROACHES

6.8 Cost benefit approaches to R&D resource allocation in the UK public sector were last carried out to any significant extent in the 1960s and early 1970s. The focus of activity was the Programmes Analysis Unit (PAU), located in the Ministry of Technology. The PAU approach aimed to assess R&D projects for programmes against the criterion of national benefit, including financial returns but extending more broadly. The basic criterion was the expected benefit/R&D cost ratio, qualified by the perceived risks and broader non-quantifiable or intangible factors. Quoting a retrospective review of the PAU's work, P M S Jones a former member of the Unit, lists a number of benefits arising from appraisal, including clarification of objectives, identification of options and 'guidance on the balance between parts of programmes and on the effect of government support or non-support' (Jones, 1989). However, the review concluded that quantitative appraisal could not give guidance on the proper total level of governmental or departmental R&D expenditure nor offer much general guidance on the split of budget between widely different sectors of activity. Jones echoes some of the statements made about *ex post* calculations of returns to R&D:

> *"Efforts to combine disparate costs and benefits into a single objective function conceal value judgements: multi-attribute analysis in which trade-offs are fully exposed, including those that defy quantification, are to be preferred."*

Jones reviews more recent work in cost-benefit analysis (for example the Sizewell inquiry) and concludes that cost-benefit analysis can provide valuable insights and perhaps clear guidance on small scale activities but is too prone to uncertainty where large scale projects or programmes with potentially wide-ranging impacts are concerned.

6.9 Similar conclusions were drawn by Norris and Vaizey (1973) and Byatt and Cohen, (1969). The approach of Norris and Vaizey was basically similar to the more recent work by Mansfield (reported above in Section 3). It started with the notion that basic research may lead to new industries, or may have smaller scale applications in industry. The method was to see what effect a notional delay in the scientific discovery would have had on the net benefits of the discovery. Net benefits were defined as the change in output *less* the costs of applied research, development, investment and manufacturing. A feasibility study of this approach found that although in some cases the economic benefits of a scientific discovery could be traced, in general it was not feasible because the interaction between science and technology could not be adequately described by the linear model assumed in the method.

PRIVATE SECTOR APPROACHES

6.10 In private companies R&D usually competes for resources with other forms of investment, although in certain sectors, such as biotechnology, new companies may be established with venture capital funds. Within the overall budget for R&D individual project choices for both planned and ongoing research need to be prioritised, again broadly in terms of investment criteria. These choices are, of course, restricted by management perceptions of the strategy and 'core competences' of the firm (Prahalad and Hamel, 1990). In the following paragraphs the application of quantitative techniques at project and portfolio level is examined; then the broader environment in which firms seek to gain economic benefit from their R&D activities is considered.

PROJECT SELECTION

6.11 There is a large body of management literature on the application of quantitative techniques to the selection of R&D projects. Much of this literature comes from the 1960s and 1970s. Baker (1975) classified the approaches used in this literature. What he terms 'objective functions' are defined as: 'systematic procedures for soliciting and integrating subjective and objective benefit data'.

These were placed in three categories:

- **Comparative models** - which require the respondent(s) to compare one proposal either to another proposal or to some subset of alternative proposals;

- **Scoring models** - which require the respondent(s) to specify the merit of each proposal with respect to each of several project characteristics (criteria), whereupon criterion scores can be aggregated to yield an overall project score; and

- **Benefit contribution models** - which require the respondent(s) to tie the projects directly to R&D objectives or to system requirements, and benefit is measured in terms of contribution to the objectives or to the requirements.

The experience of companies in applying project selection techniques has been reviewed on more than one occasion (see Baker, 1975; Liberatore and Titus, 1983; Brockhoff and Pearson, 1992). All of these reviews draw a similar conclusion: that industry has not extensively employed these techniques. An exception to this is the use of scoring models and related techniques.

6.12 The OTA study (1986) in its review of documented experience identified four categories of formal techniques.

I) SCORING MODELS

Corresponding to Baker's category above, this involves rating each project against a series of relevant decision criteria. Scores for each project are combined to give a single project score. Criteria may be economic or non-economic (eg technical merit). Approaches of this type are widely used in UK Research Council committees. Evaluations have noted that criteria relating to scientific quality normally outweigh potential economic return in the final ratings, although there is rarely a formal weighting system. It appears that scientists and technologists (including industrial members) dislike supporting projects which may not be of the highest technical quality on strategic grounds.

6.13 Paul, reporting on his experience with Shell R&D (Paul, 1992), offers a more positive view of scoring models as an approach to *ex ante* evaluation. His basic condition is that the peer panel which assigns the scores should represent

not only the peer panel of researchers but also those close to the market and product. Furthermore he insists:

- Projects have to be based on a need identified by a customer. Following in-depth discussion objectives need to be defined to facilitate checking of progress;

- Projects should be classified as Basic, Applied or Development and those categorised as Basic should not be assessed on financial criteria;

- Applied and Development projects should be prioritised by peer panels constituted as above.

He suggests the use of a matrix of criteria (derived from the Boston Consulting Group Approach) which compares *attractiveness* and *feasibility* on similar lines to the CSIRO approach described above (see Figure 1).

6.14 Other techniques have been used to add rigour to scoring approaches. Q-sorting was suggested in 1975 (Helin and Souder, 1975), whereby a group of experts directly prioritise various projects. More recently, an approach known as QFD (quality function deployment) has moved on to the use of a peer group to prioritise the *criteria* for evaluation. The technique uses matrices and decision trees to facilitate communication and simultaneously define and document customer requirements (Bossert, 1991).

II) ECONOMIC MODELS

These approaches rate projects against a series of economic criteria such as expected rate of return. The basic approach is one of capital budgeting or investment appraisal. Each indicator (eg Net Present Value, Internal Rate of Return, Return on Investment, etc) produces a quantitative measure of the attractiveness of the investment, normally discounted over time. An allowance for risk may be added independently. Despite the apparently precise economic formulation it should be stressed that the data for an approach of this type are often derived from expert opinion and are no more intrinsically valid than scoring models (which in effect they are). In addition, the different indicators (which should be used in parallel on any single appraisal) may give conflicting advice, for example in the rank ordering of a set of independent projects. Critical assumptions need to be made in adjusting for time and risk. Graves and Ringuest (1991) showed that the technical combination of these adjustments can produce biases, for example against shorter or longer term

projects. Norris and Vaizey were even more critical of such approaches. Their objections may be summarised as follows:

- As returns to R&D are typically longer term compared with other forms of investment, they will be heavily discounted and count for very little;

- Risk and uncertainty, particularly in fast-moving areas, will be substantial and very difficult to calculate.

III) CONSTRAINED OPTIMISATION OR PORTFOLIO MODELS

These models examine a mix of projects rather than individual cases and use programming techniques to allocate resources among the candidates. Optimisation is against economic objectives with specified resource constraints. High quality data are necessary.

IV) RISK ANALYSIS OR DECISION ANALYSIS

These analyses require high quality data . Such models describe the expected utility of alternative budget allocations among a set of research projects, making use of probability distributions. As noted earlier, the use of purely quantitative approaches in industry is rare, although many larger firms will go through some less formal version involving scoring and/or investment appraisal (for example, British Gas uses discounted benefit/cost ratios to prioritise). Few would regard the outcomes of these as an automatic means of selection.

STRATEGIC APPROACHES

6.15 The above discussion focused on project selection. This approach has been criticised. For example, Pearson (1975) has pointed out that these exclude alternative approaches to a problem or project opportunity which might be available but remain unidentified. Work on the accountancy treatment of R&D (Nixon, 1991) pointed out that evaluating R&D expenditures on a 'project by project' basis ignores the reduction in uncertainty associated with undertaking a portfolio of R&D projects. Nixon argued that the disaggregated approach leads to a consistent over-estimation of uncertainty which in turn leads to an inappropriate treatment of R&D in accounting procedures.

6.16 Norris and Vaizey nonetheless considered it worthwhile to carry out an economic evaluation because it forces people to think through the implications of a proposal. Furthermore, they emphasised that all branches of a company should take part in the decision. This early conclusion provides a bridge to current thinking in R&D management studies which see economic evaluation of anticipated benefits as part of a process which emphasises the importance of communications both between different functions within the company and with its outside networks of suppliers, customers, collaborators and competitors. Hence, the practice in a Japanese corporation of requiring its researchers to estimate the economic returns to their projects: not because the results will be used, but to ensure that the researchers have a business orientation and can communicate with production departments of the company.

6.17 With this is mind it is possible to reappraise the value of some of the techniques considered. Matrices and the use of scoring models can be seen as a means of bringing together personnel from different backgrounds and providing them with a channel of communication, thus facilitating horizontal relationships across the organisation. Research planning diagrams can be used to develop a consensus about the requirements of an R&D project and to help identify and anticipate problems both within the project and in the implementation or commercialisation process. As mentioned above, approaches such as quality - function-deployment (QFD) can extend to involving the customer. Risk management procedures can be used to enhance these approaches, with the emphasis on identifying what is **not** known about a project and quantifying those risks.

6.18 Other recent techniques focus on external networks. To be able to learn and benefit from R&D conducted elsewhere needs an R&D capability which is sufficiently 'state of the art'. An R&D project can thus be seen as an 'option' to become involved in a technology at a later date. This approach leads to the potential application to R&D of option-pricing theory, as used in financial markets. This technique has been explored by some large companies but little information is available in the literature which is specific to R&D (Newton, 1991).

6.19 An indication of the factors industry considers significant in answering the question 'How Much R&D?' is given in a paper of the same title (EIRMA-European Industrial Research Management Association, 1992) which reported on a workshop and questionnaire findings. First, it notes that feedback on performance is normally too late to influence subsequent allocative decisions. Second, some influences on R&D levels are driven by political,

social and technological factors beyond the control of the business. For example, there is political pressure for improved environmental performance. Third, R&D is getting closer to the customer, both geographically and organisationally. Finally, while profit growth is a strong determinant of perceptions of R&D intensity for the future, firms recognise that future investment is also influenced by current profits and the ability to pay.

6.20 Allocation of resources is seen by EIRMA as a matter of achieving balanced top-down (corporate) and bottom-up (business) allocation. Again, emphasis is placed on organising R&D to align with business and markets **with effective project selection and feedback on the benefits achieved**. Managing the total innovation process is as important as selection of projects: much work has been done, for example, on the role of product champions and on organisational structures. Considering which companies have the capability to appropriate the benefits is another important consideration.

6.21 The lesson which might be drawn for publicly-funded R&D here is that whatever the utility of ex ante assessment techniques, they are a necessary but not a sufficient instrument to achieve greater economic benefits from R&D. Achievement of that objective would, in addition, require organisational change involving the managers of the R&D and their relationship with the firms which would ultimately be responsible for realising those benefits.

7. CONCLUSIONS

6.22 Given the uncertainty involved in forecasting the future, and the complexity of the innovation process, it is hardly surprising that **ex ante** appraisal of R&D is even less likely than **ex post** evaluation to give accurate and detailed information on rates of return such that choices may be made across widely different areas of R&D. Nonetheless there are a number of useful lessons to be derived from private sector practices in this area which offer scope to put R&D decision-making in the public sector onto a more rational basis and, more importantly, to increase the likelihood that there will be an economic return to Government-funded R&D. The following points can be made:

- Current best practice for assessment in government R&D requires that programmes should undergo a systematic appraisal to ensure that there is a rationale for support and that objectives are clear. In support of this approach, one possibility would be, for example, taking into account economic benefit to the United Kingdom as a horizontal consideration, wherever possible, for Government R&D; and for this to feature in appraisal exercises. This is not to say that there should be any diminution of the other objectives, but rather that those performing an appraisal should include an explicit statement about expected economic consequences and the appropriability of R&D results. In some cases these may be zero or even negative but outweighed by other benefits. This requirement would have the benefit of focusing programmes and perhaps re-orienting them towards taking advantage of opportunities for wealth creation.

- In considering the return to R&D the question of **appropriability** should always be in mind. It may not be sufficient to identify an area as being of high promise - there should be a reasonable prospect of its being exploited in the United Kingdom to a sufficient level to justify the investment.

- There are a number of techniques available for structuring expert opinion and for applying the investment appraisal metaphor to R&D. None offers a unique solution but most could help to organise thinking and improve decision-making. The use of scoring models in industry is testimony to this. Those performing appraisals should be encouraged to use these approaches, perhaps as a 'battery of tests' in order to inform the exercise.

- Many of the problems encountered in these approaches stem from a lack of adequate data. Systematic analysis of past performance is one way to improve this situation. This reinforces the need to treat assessment as a cycle with evaluation informing appraisal.

- The investment metaphor can also usefully be applied to R&D which is directed at non-monetary benefits such as improved health, safety and welfare generally.

- Fostering an investment-oriented approach among those performing appraisals is unlikely to be achieved solely by production of guidelines. An active strategy of training and support is needed.

- In the final analysis, if the objective is not simply to measure but is also to optimise and increase the contribution which government-supported R&D makes to wealth creation, then it is insufficient to reallocate that R&D. In industry, project selection has come to be seen as a small subset of strategic and organisational issues. This is also true for Government. Economic benefit can only be realised through innovation and commercialisation. A strategy for increasing this requires close examination of the entire organisational structure of Government and public sector institutions, with particular emphasis on the linkages to industry and sources of finance.

TABLE 1 INDUCTION TIMES FOR EXPLOITATION

PRODUCT	INTERVAL BETWEEN INVENTION AND EXPLOITATION (YEARS)	PRODUCT	INTERVAL BETWEEN INVENTION AND EXPLOITATION (YEARS)
Safety razor	9	Jet engine	14
Fluorescent lamp	79	LP record	3
TV	22	Magnetic recording	5
Wireless telegraph	8	Perspex	3
Triode vacuum tube	7	Nylon	11
Spinning jenny	5	Power steering	6
Watt steam engine	11	Radar	13
Ball point pen	6	Streptomycin	5
DDT	3	Terylene	12
Freon refrigerant	1	Xerography	13
Gyro compass	56	Zipper	27
Hardening of fats	8		

Source: J. D. Birchall, FRS.

TABLE 2 ECONOMETRIC STUDIES OF THE PRODUCTIVITY RETURN AGRICULTURAL RESEARCH IN THE UNITED STATES

AUTHOR (DATE)	COMMODITY	TIME PERIOD	RATE OF RETURN
Griliches (1964)	Aggregate output	1949-59	35-40
Peterson (1967)	Poultry	1915-60	21
Evenson (1968)	Aggregate	1949-59	47
Cline (1975)	Aggregate	1939-48	41-50
Knutson and Tweeten	Aggregate	1949-58	39-47
(1979)		1959-68	32-39
		1969-72	28-35
Bredahl and Peterson	Cash grain	1969	36
(1976)	Poultry	1969	37
	Dairy	1969	43
	Livestock	1969	47
Davis (1979)	Aggregate	1949-59	66-100
		1964-74	37
Evenson (1979)	Aggregate	1868-1926	65
		1927-50	95 (applied R&D)
		1927-50	110 (basic R&D)
		1948-71	45 (basic R&D)
Davis and Peterson	Aggregate	1949	100
(1981)		1954	79
		1959	66
		1964	37
		1969	37
		1974	37
Norton (1981)	Poultry	1969	27
	Dairy	1969	56
	Livestock	1969	30
	Cash grain	1974	44
	Poultry	1974	33
	Dairy	1974	66

Source: *R D Weaver, "Federal R&D and US Agriculture: An Assessment of the Role and Productivity Effects", paper presented at the National Academy of Sciences Workshop on "The Federal Role in Research and Development", Nov. 21-22, 1985, p.27.*

TABLE 3 UK BALANCE OF TRADE IN AEROSPACE AND MILITARY AIRCRAFT

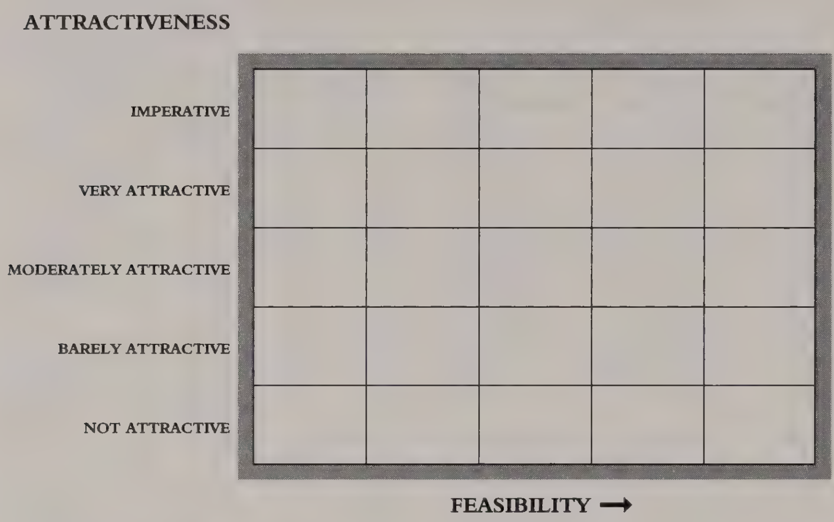
	VISIBLE TRADE BALANCE (£M)		MILITARY AIRCRAFT AND PARTS (£M)		
YEAR	UK ECONOMY	AEROSPACE	EXPORTS	UK IMPORTS INDUSTRY	BALANCE
1981	3252	831.4	183	11	172
1982	1910	1125.1	216	3	213
1983	-1537	1016.5	260	0	260
1984	-5336	857.1	212	54	158
1985	-3345	1061.4	174	18	156
1986	-9559	1931.6	192	3	189
1987	-11582	2371.3	326	0	326
1988	-21480	1690.6	813	346	467
1989	-24683	3222.5	1524	384	1140
1990	-18809	1664.3	1206	316	890
1991	-10290	2501.7	1367	328	1039

Sources: *SBAC; Monthly Digest of Statistics; Defence Statistics 1992, Ministry of Defence.*

Notes: *(i) UK economy figures are seasonally adjusted*

(ii) Exports and imports for the aerospace industry comprise all military and civil aerospace products. The trade in military aircraft and parts does not include guided weapons, missiles and parts, nor does it include the group classified as additional aerospace equipment.

FIGURE 1: A TYPICAL SCORING MODEL



CRITERIA:

ATTRACTIVENESS

- Importance of the technologicalperformance relative to the market
- Size of the market (or market potential)
- Projected market growth
- Amount of environmental damage avoided
- Enhanced social amenity
- Health and safety improvement

FEASIBILITY

- Fertility of research field
- Scientific competence
- Position of current technology on "S-curve"
- Chances of success

Source: *Paul, (1992)*

ANNEX 1

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